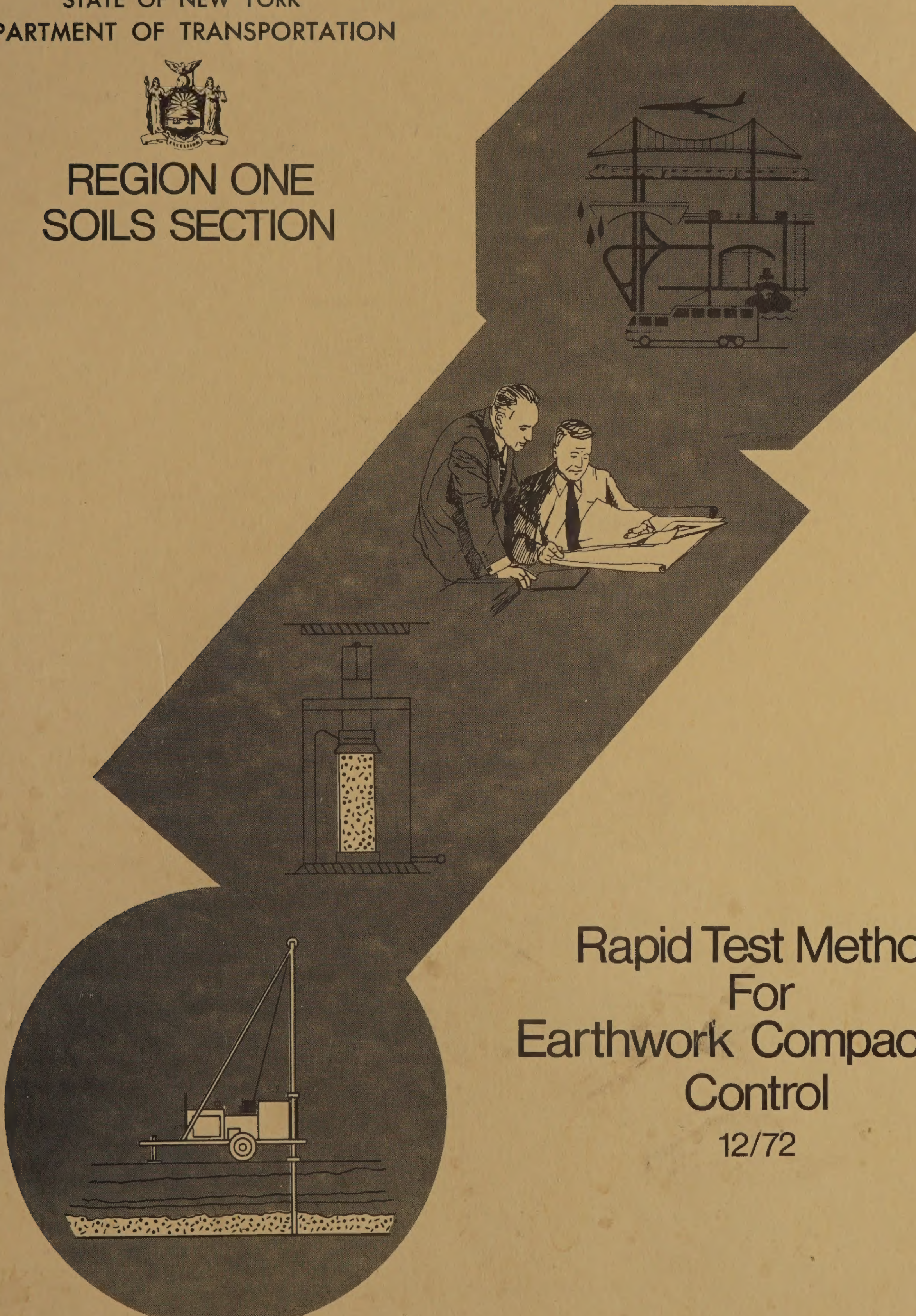
STATE OF NEW YORK
DEPARTMENT OF TRANSPORTATION

REGION ONE
SOILS SECTION



Rapid Test Method For Earthwork Compaction Control

12/72

RAPID TEST METHOD
FOR
EARTHWORK COMPACTION CONTROL

by

William H. Peak

NOVEMBER, 1972

REGION ONE SOILS SECTION
NEW YORK STATE DEPARTMENT OF TRANSPORTATION
50 WOLF ROAD, ALBANY, NEW YORK 12205

FOREWARD

The current most widely used practice for earthwork compaction control is to measure the field density and compare it to the maximum density obtainable for this material in a specified laboratory compaction test. The control is generally in terms of dry density, which requires the measurement of the field moisture content even when moisture determinations are not an explicit requirement of the control.

Normally, the desired implementation of any compaction control procedure rests on the capabilities of the inspection personnel, who are required to perform a series of rather complex mathematical calculations. These calculations are based, in part, on making rational engineering judgments and interpolations. Many control problems, it has been found, are directly related to the multiplicity of the calculations and their interrelationship with required interpolations.

Performance of a compaction control test, based on present procedures, consumes a considerable amount of time. This severely limits the number of tests that can be accomplished and delays the reportable results at a time when rapid substantiation of conformance is essential.

Ideally, any new test method for earthwork compaction control should; (1) retain the basic fundamental elements of compaction control that have gained widespread recognition and acceptance; (2) eliminate non-essential procedures that have no quantitative application to the control; (3) simplify the test procedures so that technical, judgment and interpolation errors are reduced to a minimum or eliminated entirely, and; (4) consume a minimum of time to perform without sacrifice to the quality of the control.

Individuals, agencies and highway departments are invited, even urged, to test and evaluate the RAPID TEST METHOD FOR EARTHWORK COMPACTION CONTROL developed by William H. Peak and described herein to determine if the objectives desired have been essentially achieved.

John P. Rumsey
Regional Soils Engineer
N.Y.S. Dept. of Transportation

ABSTRACT

More dependable test results can be obtained in *less time* by the compaction control test method described in this report.

Moisture determinations are *usually unnecessary* and conversions from wet density to dry density are *never required.*

New procedures and equipment have been devised to *simplify* this method. The test *does not rely* on estimations, assumptions or judgments (a major deficiency of other rapid test methods).

The procedures are founded on the *well-known principles* of compaction control that measure the FIELD DENSITY and compare it to the MAXIMUM DENSITY obtainable for this material in a specified LABORATORY DENSITY test.

The FIELD DENSITY is determined with a *special slide rule* from the volume of the hole measured by a *sand replacement volumeter.*

The LABORATORY DENSITY (and moisture content when necessary) is evaluated with reduced weighings and no calculations by the use of *fixed weight density cylinders and moisture tares.*

The MAXIMUM DENSITY obtainable, taken from moisture-density curves and compiled in *compaction control tables,* can be compared with the FIELD DENSITY without any calculations or interpolations required.

When the FIELD DENSITY is increased above the minimum specified density, moisture content determinations are eliminated and the time necessary to perform a test decreases. This unique feature of the Compaction Control Method creates an incentive for the Contractor, who is delayed awaiting test results, *to supply more thoroughly and uniformly compacted earthwork materials.*

CONTENTS

NEW FEATURES

THEORY

This method utilizes a computational system based on Statewide Compaction Control Curves that permits a majority of compaction tests to be performed without requiring moisture content determinations.

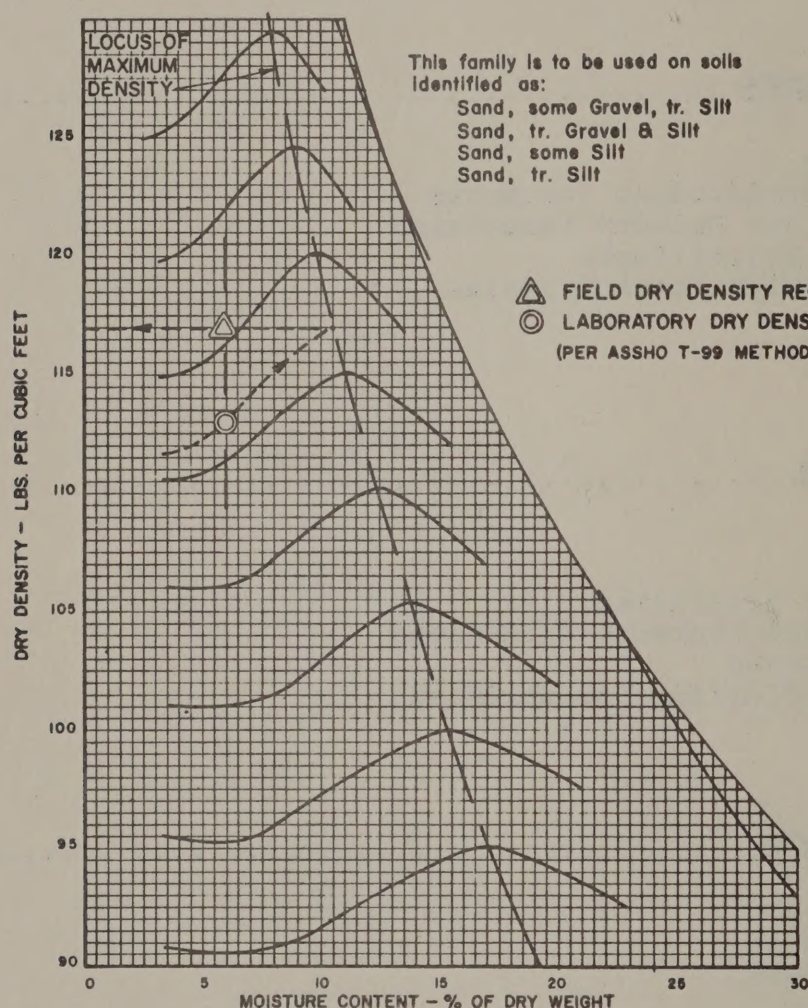


Figure 1

As shown in Figure 1, the Statewide Curves are developed on a Dry Density vs. Moisture Content basis. Using an assumed Laboratory Dry Density (113 lbs/cu. ft.) and a Moisture Content (6%) a point can be plotted on the graph. Through this point a curve is drawn parallel and similar to the adjacent curves. The Maximum Dry Density (117 lbs/cu. ft.) is obtained from the point where this curve intercepts the Locus of Maximum Density. Since the moisture content for the laboratory and the field dry density is identical, the

intersection of this moisture content value and the maximum dry density value is the point where the Field Dry Density would plot to be equivalent to the Maximum Dry Density. In Figure 1 this point is called the *Field Dry Density Required.*

Any point on this graph also represents a certain wet density - the product of the dry density value and of one plus the moisture content value. Points of equal wet density arrange in curves trending from the upper left to the lower right. Figure 2 shows the relationship between the wet density curves, the compaction control curves and the points as plotted in Figure 1.

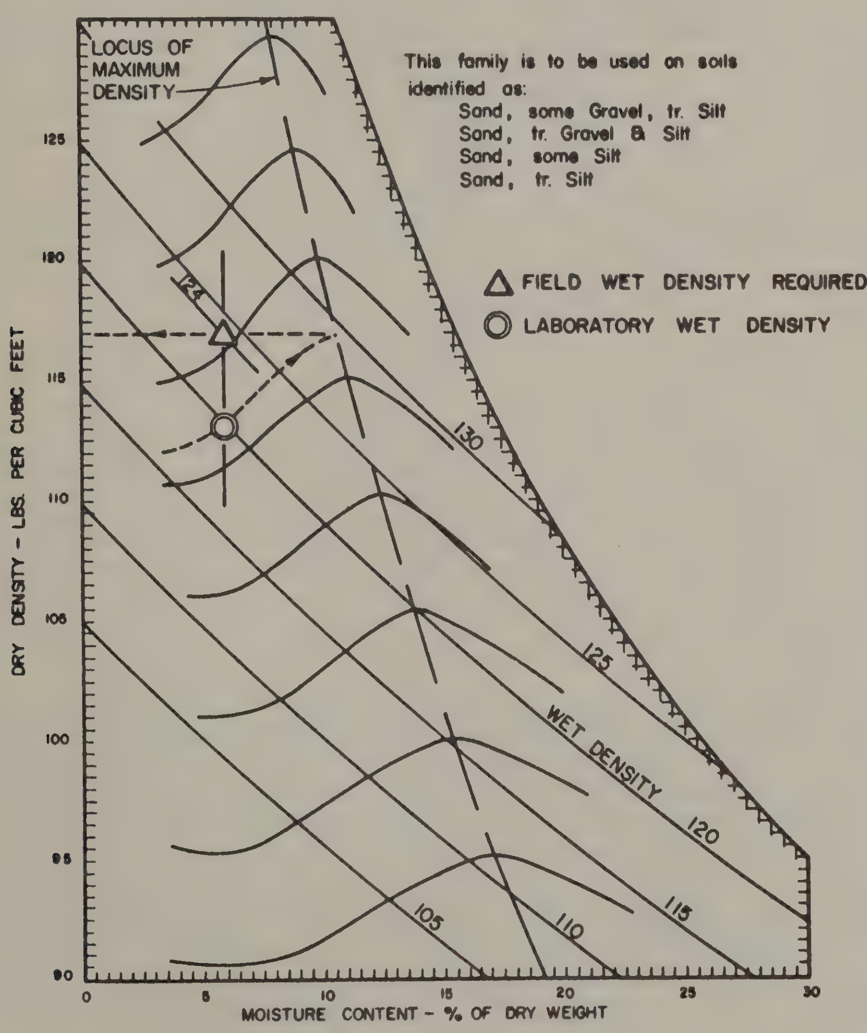


Figure 2

Using this graph it can be seen that if the Laboratory Wet Density (120 lbs/cu. ft.) and the Moisture Content (6%) is known, the *Field Wet Density Required* (124 lbs/cu. ft.) to obtain the Maximum Dry Density can be established.

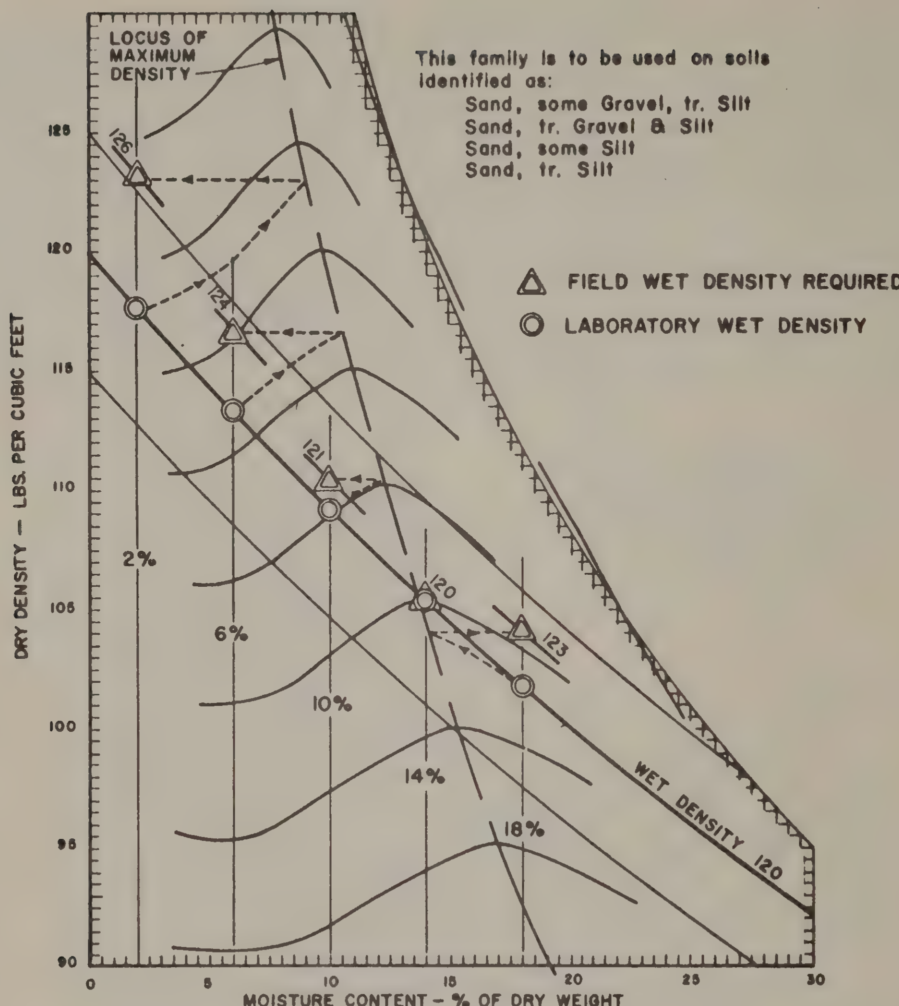


Figure 3

Figure 3 shows that points of equal Laboratory Wet Density (used 120 lbs/cu.ft.) and varying moisture contents develop different values for the Maximum Dry Density and the Field Wet Density Required. The range of varying moistures and these corresponding values can be limited as follows:

1. *A 2 percent minimum limit* - No normal embankment material will be found dryer than 2 percent (a higher minimum limit may be established by the Regional Soils Engineer).

2. *A maximum of 4± percent above Optimum* - Embankment materials with moistures approaching this limit will rut excessively and no compaction tests will be taken.

Within these limits, Figure 3 shows that the *highest* Field Wet Density Required (126 lbs/cu. ft. for a Laboratory Wet Density of 120 lbs/cu. ft.) occurs at the minimum moisture content of 2 percent. Accordingly, if the Field Wet Density is greater than the Field Wet Density Required at the 2 percent moisture content, *the compaction test passes regardless of the actual moisture content of the soil.*

As the moisture content is increased over 2 percent, the Field Wet Density Required to satisfy the specification requirements, decreases until the *lowest* Field Wet Density Required (120 lbs/cu. ft.) is reached. This is at the point where the wet density curve crosses the locus of maximum density (or optimum moisture). It then increases on the wet side of the optimum moisture. This means that, if the Field Wet Density is lower than the Field Wet Density Required at the optimum moisture content, *the test fails regardless of the actual moisture content of the soil.*

If the field wet density of the soil is between the highest and the lowest Field Wet Density Required, a moisture content determination is necessary to evaluate the test. From the known Laboratory Wet Density and the Moisture Content, the actual Field Wet Density Required can be obtained and compared with the measured Field Wet Density for a pass-fail decision.

The spread between the highest and lowest Field Wet Density Required may be reduced by increasing the minimum assumed moisture content. This will result in a further reduction in the number of moisture determinations that are necessary for compaction control. The *Regional Soils Engineer* has the authority to set a minimum moisture content higher than 2 percent. In doing this he should be guided by:

1. The moisture contents determined for the embankment material being utilized.
2. The uniformity of the source of embankment material.
3. Previous experience in similar materials.

The moisture content selected as the minimum should be lower than any moisture content the embankment material in question can reasonably be expected to have.

The Field Wet Densities Required for all combinations of laboratory wet density and moisture content may be presented in graphic form or, as presented in this method, the values may be compiled and tabulated for easier reference.

SAND REPLACEMENT VOLUMETER

Complete instructions for the use of the volumeter are given in the Test Method Section of this report. Essentially, the volume of the hole is measured by reading the volume of the sand remaining after the hole is filled.

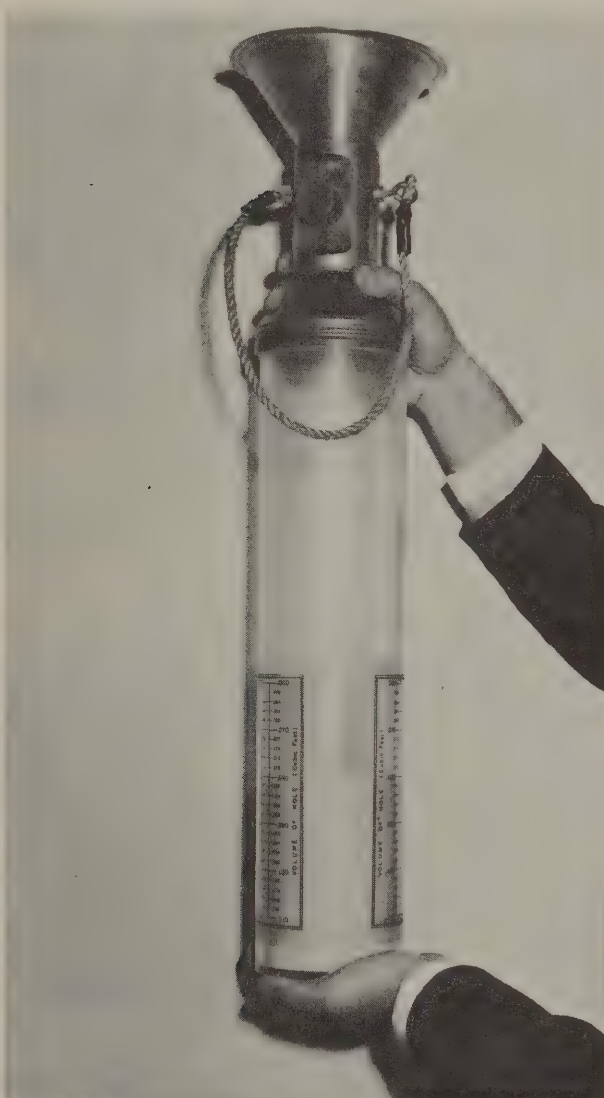


Figure 4

Since the volume of the sand remaining in the container is subject to changes caused by the manipulation of the apparatus, a study was made to evaluate the dependability of reading the top surface of the sand to find the volume of the hole. Using the technique as outlined in the Test Method, it was found that individual readings will not vary more than .001 cubic foot and that the average of the 3 readings will vary less than .0005 cubic foot. The precision capability of this instrument is greater than the precision of the sands that may be used. (1±% Bulk Density)

This direct reading apparatus eliminates all weighings, corrections and calculations usually associated with the measurement of the hole by the normal sand cone method.

Because in effect, the sand is calibrated each time the volumeter is filled for use, the errors due to the variability in the unit weight of the sand are also eliminated.

The normal sand replacement method has, in the past, been used as the standard of accuracy to evaluate other volume measurement equipment. *Measurements by this volumeter are simple, rapid and when compared under actual field conditions, have been found to be more accurate than the unit weight method.*

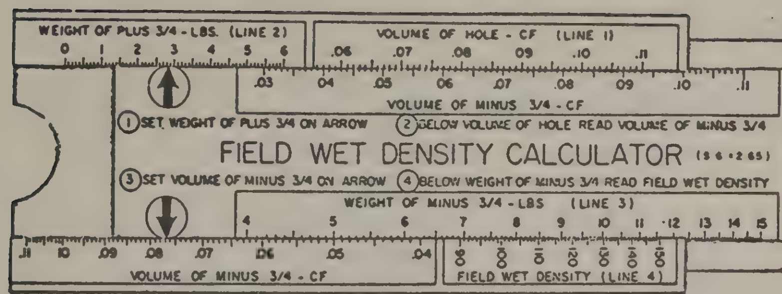


Figure 5

FIELD WET DENSITY CALCULATOR

The one computation (Field Wet Density) needed in this method is resolved by this slide rule. The Density Correction Curves for Plus 3/4 material (Figure 6) and several steps in present methods are also eliminated by this procedure.

Instructions, imprinted on the face, are simple, concise and integrated with the Compaction Control Data Sheet. The limits set by the scales on the slide rule are designed to prevent errors that are outside the parameters of this test method.

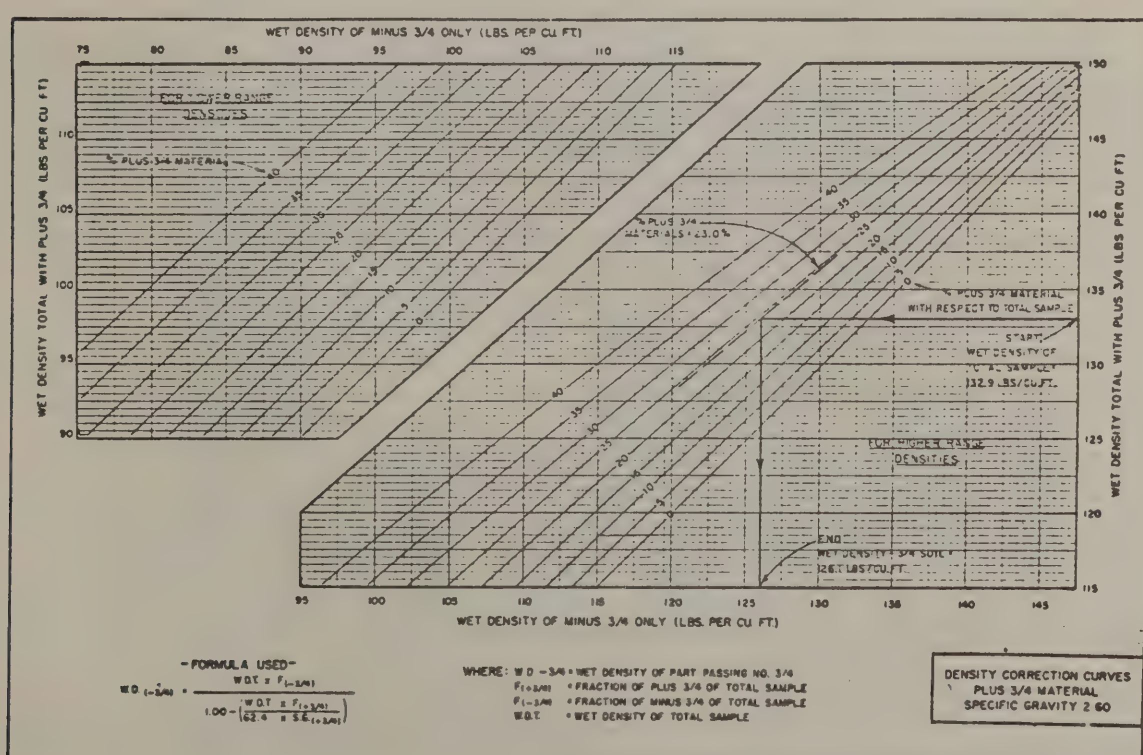


Figure 6

FIXED WEIGHT TARES

The moisture tare and the density cylinder weights have been standardized to further simplify this test method.

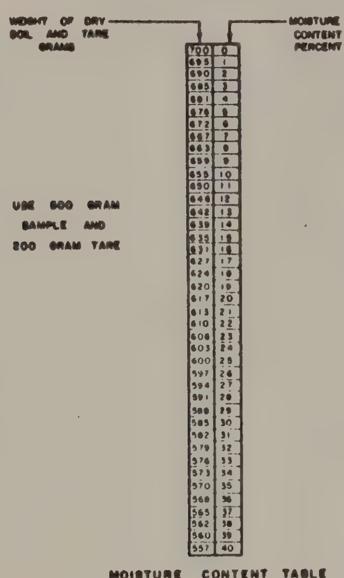


Figure 7

With a fixed moisture tare weight of 200 grams and a fixed moist soil weight of 500 grams the moisture content can be found from the Percent of Moisture Table (Figure 7) by observing the total weight of dry soil and tare only.

The fixed weight of the compaction cylinder at 4 lbs. eliminates the need to compute the laboratory wet density. The Compaction Control Tables (Figure 8) are arranged to find the required wet density from the total weight of the cylinder and soil.

The weighing of the cylinder and soil to the nearest one tenth of a pound introduces a minor variance. Using the 1/30 cubic foot density cylinder, the observations of laboratory wet density may be 1 1/2 lbs. per cubic feet more or less than the actual wet density. EXAMPLE:

(Wt. Cylinder and Soil - Wt. Cylinder) 30 = Laboratory Wet Density

$$(8.3 - 4.0)30 = 129$$
$$(8.2 - 4.0)30 = 126$$
$$(8.1 - 4.0)30 = 123$$

The Compaction Control Tables supply the values of 126 lbs/cu. ft. for all laboratory wet densities between 127.5 and 124.5 lbs/cu. ft. The result is that for any measured laboratory wet density these tables indicate wet densities that are slightly higher or lower than the actual wet densities required. The greatest difference however is $1\pm$ percent from the specified percent of maximum dry density. This variance is well within the precision of this, or any other test method.

COMPACTION CONTROL TABLES

Tabulations of the Field Wet Densities Required to obtain a specified percent of maximum dry density have been prepared to eliminate the otherwise necessary computations and graphic interpolations. These tables, (Figure8) replace the Statewide Compaction Control Curves. They cover the full range of soil types and moisture contents normally encountered in earthwork construction in New York State. Similar tables can be developed to apply to any soil where the moisture density relationships are known.

TABLE I — SANDS AND SANDS CONTAINING MINOR AMOUNTS OF GRAVEL AND SILT

WEIGHT OF CYLINDER AND SOIL - LBS	MAX DEN SPECIFIED	MOISTURE CONTENT 2	4	6	8	10	12	14	16	18	20
9.0	100%										
	95%										
	90%										
.9	100%										
	95%										
	90%										
.8	100%										
	95%										
	90%										
.7	100%										
	95%										
	90%										
.6	100%	143	141	140	139	140					
	95%	136	134	133	132	133					
	90%	129	127	126	125	126					
.5	100%	140	139	137	136	137					
	95%	133	132	130	128	130					
	90%	126	125	123	121	123					
.4	100%	137	136	135	133	132	134				
	95%	130	129	128	127	126	128				
	90%	123	122	121	120	119	121				
.3	100%	134	133	132	131	129	130	131			
	95%	128	127	126	125	123	124	125			
	90%	121	120	119	118	116	117	118			
.2	100%	131	130	129	128	127	126	127	129		
	95%	125	124	123	122	121	120	121	123		
	90%	118	117	116	115	114	113	114	116		
.1	100%	129	128	127	125	124	123	123	125		
	95%	123	122	121	119	118	117	117	119		
	90%	116	115	114	112	112	111	111	113		
8.0	100%	126	125	124	123	121	120	120	121	123	
	95%	120	119	118	117	115	114	114	115	117	
	90%	113	112	112	111	109	108	108	109	111	
.9	100%	122	122	121	120	119	118	117	118	118	
	95%	116	116	115	114	113	112	111	112	112	
	90%	110	110	109	108	107	106	105	106	106	
.8	100%	119	119	118	117	116	116	115	115	115	116
	95%	113	113	112	111	110	110	109	109	109	110
	90%	107	107	106	105	104	104	103	103	103	104
.7	100%	116	116	116	115	114	113	112	111	111	112
	95%	110	110	110	109	109	108	107	106	106	107
	90%	104	104	104	103	103	102	101	100	100	101
6	100%	112	112	112	112	111	110	109	109	109	108
	95%	107	107	107	107	106	105	104	104	104	103
	90%	101	101	101	101	100	99	98	98	98	97
5	100%	109	109	109	109	108	107	106	106		
	95%	104	104	104	104	103	102	101	101		
	90%	98	98	98	98	97	96	95	95		
4	100%	106	106	106	106	106					
	95%	101	101	101	101	101					
	90%	95	95	95	95	96					
3	100%	104	104	104	104						
	95%	99	99	99	99						
	90%	94	94	94	94						
2	100%	101	101	101							
	95%	96	96	96							
	90%	91	91	91							
1	100%										
	95%										
	90%										
70	100%										
	95%										
	90%										

TABLE I

TABLE II — TILLS, SILTS, CLAYS, AND WELL GRADED GRAVELS

WEIGHT OF CYLINDER AND SOIL - LBS	MAX DEN SPECIFIED	MOISTURE CONTENT 2	4	6	8	10	12	14	16	18	20	22	24	26	28	30
9.0	100%	155	152	150	151											
	95%	147	145	143	144											
	90%	139	137	135	136											
.9	100%	153	150	147	147	151										
	95%	146	143	140	140	144										
	90%	138	135	132	132	136										
.8	100%	151	148	146	144	146										
	95%	144	141	139	137	139										
	90%	136	133	131	130	131										
.7	100%	149	146	144	142	141	146									
	95%	142	139	137	135	134	136									
	90%	134	131	130	128	127	129									
.6	100%	148	144	142	140	138	138	142								
	95%	140	137	135	133	131	131	135								
	90%	133	130	128	126	124	124	128								
.5	100%	146	142	140	138	136	135	136	139							
	95%	138	135	133	131	129	128	129	132							
	90%	131	128	126	124	122	121	122	125							
.4	100%	143	140	138	136	134	133	132	134	136						
	95%	136	133	131	129	128	127	126	128	129						
	90%	129	126	124	122	121	120	119	121	122						
.3	100%	141	138	136	133	132	130	129	129	130	133					
	95%	134	131	129	127	126	124	123	123	124	127					
	90%	127	124	122	120	119	117	116	116	117	120					
.2	100%	139	136	133	131	130	129	128	127	126	126	128	130			
	95%	132	129	127	125	124	123	122	121	120	120	122	124			
	90%	125	122	120	118	117	116	115	114	113	113	115	117			
.1	100%	138	135	132	130	128	127	125	124	124	123	123	124	126		
	95%	131	128	126	124	122	121	119	118	118	117	117	118	120		
	90%	124	121	119	117	115	114	113	112	112	111	111	112	113		
8.0	100%	136	132	130	128	126	124	124	123	122	121	121	120	120	121	
	95%	129	126	124	122	120	118	118	117	116	115	115	114	114	115	
	90%	122	119	117	115	113	112	112	111	110	109	109	108	108	109	
.9	100%	133	130	127	126	124	123	122	121	120	120	119	119	118	118	117
	95%	127	124	121	120	118	117	116	115	114	114	113	113	112	112	111
	90%	120	117	114	113	112	111	110	109	108	108	107	107	106	106	105
8	100%	130	127	125	124	122	120	120	119	118	118	117	116	116	115	115
	95%	124	121	119	118	116	114	114	113	112	112	111	110	110	109	109
	90%	117	114	113	112	110	108	108	107	106	106	105	104	104	103	103
.7	100%	128	125	123	122	120	119	118	117	117	116	115	114	114		
	95%	122	119	117	116	114	113	112	111	111	110	109	109	109		
	90%	115	112	111	110	108	107	106	105	105	104	103	103	103		
6	100%	125	123	121	119	118	117	116	116	115	114	113	113			
	95%	119	117	115	113	112	111	110	110	109	109	108	108			
	90%	112	111	109	107	106	105	104	104	103	103	102	102			
.5	100%	122	120	119	117	116	115	114	113	113	112	111				
	95%	116	114	113	111	110	109	109	108	108	107	106				
	90%	110	108	107	105	104	103	103	102	102	101	100				
4	100%	120	118	116	115	114	113	112	112	111	110	110				
	95%	114	112	110	109	109	108	107	107	106	105	105				
	90%	108	106	104	103	103	102	101	101	100	99	99				
3	100%	117	116	114	112	111	110	110	109	109	109					
	95%	111	110	109	107	106	105	105	104	104	104					
	90%	105	104	103	101	100	99	99	98	98	98					
.2	100%	115	113	112	111	110	109	109	108	108						
	95%	109	108	107	106	105	104	104	103	103						
	90%	103	102	101	100	99	98	98	97	97						
.1	100%															
	95%															
	90%															
70	100%															
	95%															
	90%															

TABLE II

FIELD WET DENSITIES REQUIRED

(TO OBTAIN THE MAXIMUM DENSITY SPECIFIED)

EXAMPLE

DATA	SOLUTION
SOIL TYPE .... SILT	COMPACTION CONTROL TABLE .. II
WT CYLINDER & SOIL .. 8 I LBS	HIGHEST WET DEN REQUIRED .... 124 LBS/CF
MAX DEN SPECIFIED .. 95%	LOWEST WET DEN ALLOWED .... 117 LBS/CF
MIN MOISTURE USED .. 8 %	

NEW YORK STATE
DEPARTMENT OF TRANSPORTATION

COMPACTION CONTROL TABLES

FORM I

Figure 8

EVALUATION

SCOPE

In order to be viable, a new procedure or test method must exhibit real and positive benefits if it is to gain acceptance. This study compares the compaction control method presently used in New York State with the method as proposed in this report.

For the purpose of evaluation, the test records of three recently completed highway construction projects were utilized. The particular projects were selected to provide a large range of embankment materials, construction procedures and testing techniques.

The analysis includes:

1. A determination of the errors in computations and interpolations that are eliminated by this method.
2. A finding of the number of compaction tests in which the moisture content would not have been required.
3. An estimate of the time saved by utilization of the new test method.
4. An examination of the simplification accomplished by this method.

DATA

	Project 1	2	3	Total
1. Tests Observed	541	699	302	1542
2. Tests With Errors	70	112	143	325
3. Valid Tests Compared	471	587	159	1217
4. Moistures Not Required	429	268	106	803

ERRORS ELIMINATED

From a total of 1542 tests, 325 were found to have at least one error in computation or interpolation that would not have occurred if the rapid test method had been used. (For this study, a discrepancy that resulted in a value greater than 1$\pm$ percent from the true percent of maximum density obtained, was considered an error). Although only a small percentage of the errors found would have affected a pass-fail decision, *the high incidence of errors clearly shows the need to reduce the complexity of the present method.*

MOISTURES ELIMINATED

Using a minimum moisture content of 2 percent, a total of 803 moisture determinations would not have been necessary on these 3 projects. The test records used in this evaluation covered a 4 year period encompassing a variety of weather conditions. A moisture content below 6 percent was not recorded for the tills, silts and clays that were utilized for embankments. Using a 6 percent minimum moisture content for these materials, a total of 1035 moisture tests would not have been necessary.

On Project No. 1, where a review of other construction project records indicated that the test results were most typical, *98 percent of the compaction tests taken would not have required moisture determinations.*

In view of these findings, the need for special equipment or for further research to speed moisture content determinations for compaction control purposes, is questionable.

TIME SAVED

An attempt to compare the time required by each method resulted in the following approximations:

1. The time necessary to travel to the test site, dig the hole, fill the hole with sand and return to the soils laboratory varies considerably but is the same for either test method.
2. Assuming a soil sample can be dried in about 45 minutes by the open flame method, the time necessary to obtain a test result by the present method (after the inspector returns to the soils laboratory) is 1 hour.
3. A test result using the new test method procedures, when no moisture content is required, can be obtained (after the inspector returns to the soils laboratory) in 10 minutes.

Considering that the present method requires an additional time to calibrate the sand and a longer time to check the test results, it is estimated that the *total time saved will be in excess of 1 hour.*

Using 1 hour less per test when moistures are not required, a total of 530 man hours (98% X total number of tests) could have been saved for more productive use on Project No. 1.

Since the Contractor is sometimes delayed awaiting test results, the time saved by this method can also increase the productivity of his operations.

SIMPLIFICATION ACCOMPLISHED

Figure 9 demonstrates the reduction in the number of steps required by this method.

A COMPARISON OF STEPS REQUIRED

PRESENT TEST METHOD	RAPID TEST METHOD (NO MOIST. REQ'D)
SAND CALIBRATION (EVERY 10+ TESTS)	
1 Weigh Sand Cone and Sand (Before)	
2 Weigh Sand Cone and Sand (After)	
3 Subtract 1-2 = Weight Sand in Cone	
4 Weigh Sand Cone and Sand (Before)	
5 Weigh Sand Cone and Sand (After)	
6 Subtract 4-5 = Weight Sand	
7 Record Weight Sand in Cone 3	
8 Subtract 6-7 = Weight of Sand in Container	
9 Weigh Mold Filled with Water	
10 Weigh Mold	
11 Subtract 9-10 = Weight of Water	
12 Divide 11÷62.4 = Volume of Mold	
13 Divide 8÷12 = Density of Sand	
VOLUME OF HOLE	
14 Weigh Sand Cone and Sand (Before)	
15 Weigh Sand Cone and Sand (After)	
16 Subtract 14-15 = Weight Sand Used	
17 Record Tare Volume Correction 3	
18 Subtract 16-17 = Net Sand in Hole	
19 Record Sand Calibration Factor	
20 Divide 18÷19 = Net Volume of Hole	1 Record Volume of Hole (Volumeter)
FIELD DENSITY -3/4	
21 Weigh Soil and Tare	2 Weigh Plus 3/4
22 Record Weight of Tare	3 Weigh Minus 3/4
23 Subtract 21-22 = Weight of Soil	
24 Divide 23÷20=Field Wet Density Plus 3/4	
25 Weigh Plus 3/4 and Tare	
26 Record Weight of Tare	
27 Subtract 25-26 = Weight of Plus 3/4	
28 Divide 27÷ 23 = % Plus 3/4	
29 Interpolate Using 24 and 28 = F.W.D. - 3/4	
30 Weigh Wet Soil and Tare	
31 Weigh Dry Soil and Tare	
32 Record Weight of Tare	
33 Subtract 30-31 = Weight of Water	
34 Subtract 31-32 = Weight of Dry Soil	
35 Divide 32÷33 x 100 = Moisture Content	
36 Divide 29÷ (1+MC) = Field Dry Den. -3/4	4 Record Field Wet Den. -3/4 (Slide Rule)
LABORATORY DENSITY	
37 Weigh Cyl. and Soil	5 Weigh Cyl. and Soil
38 Record Weight of Cylinder	
39 Subtract 37-38 = Weight of Soil	
40 Multiply 39 x 30 = Laboratory Wet Den.	
41 Divide 40÷ (1+MC) = Laboratory Dry Den.	
TEST ANALYSIS	
42 Interpolate Using 41 and 35 = Max. Den.	6 Record % Max. Den. Required
43 Interpolate Optimum Moisture	7 Record Minimum Moist. Content
44 Divide 36÷42 x 100 = % Max. Den. Obtained	8 Record Highest Wet Den. Req'd. (Table)
45 Record % Max. Den. Required	9 Record Lowest Wet Den. Allowed (Table)

Figure 9

Test results by the present method are dependent on the accuracy of *45 separate entries including 16 weighings and 21 calculations*

Test results by the rapid method are dependent on the accuracy of *9 separate entries including 3 weighings and 1 calculation*

RAPID TEST METHOD FOR EARTHWORK COMPACTION CONTROL

This method of test describes the procedure for rapidly determining whether the density obtained by the compaction operations conforms to the requirements of the New York State Department of Transportation Standard Specifications.

SUMMARY OF METHOD

The test consists of the following steps which are fully explained later in this test method:

1. Measuring the Field Wet Density of the soil in the layer that has just been placed and compacted.
2. Measuring the wet weight of a 1/30 cu. ft. volume of the soil after compacting it in a cylinder in accordance with AASHO T-99, Method C.
3. Determining whether a test passes or fails by comparing the Field Wet Density against the Field Wet Density Required (Form 1 - Front).

In some cases the moisture content has to be found in order to determine whether a test passes or fails (Form 1 - Back).

EQUIPMENT

Equipment necessary for compaction control testing on projects supervised by State Forces is issued by the Regional Soils Engineer.

PROCEDURE

The Compaction Control Data Sheet (Form 2) is used to record the test information. Before starting the test enter the data required at the top of the form.

<u>FILL THE VOLUMETER</u> Set the <u>empty</u> apparatus with the stopcock open, on a firm level area with the cone end up. Fill the container completely by pouring the sand into the cone. Keep the cone full until the sand stops flowing into the container. Close the stopcock carefully and pour off the excess sand remaining in the cone. (If the Volumeter is subject to movement or vibrations during the filling operation, remove all the sand and start over).

<u>DIG THE HOLE</u> Remove all loose material from the top of the layer to be tested. Level a small area and set the base plate firmly in place. Dig a hole through the plate opening approximately equal in diameter to the opening. The hole should extend to a depth of at least 4 inches and preferably 6 inches below the bottom of the plate. The volume of the hole should be between .10 and .06 cubic feet. Place all the material removed in a friction - top gallon can and cover in order to keep moisture loss to a minimum.

<u>LINE 1 MEASURE VOLUME OF HOLE</u> - Set the cone end on the base plate and open the stopcock. After the sand stops flowing into the hole close the stopcock carefully. (The test is invalid if the apparatus is subject to movement or vibrations during the filling of the hole.)

<u>READ THE VOLUME</u> Hold the Volumeter vertically with the cone end up. Invert it momentarily and return to the original position. Gently shake (do not jar) the apparatus horizontally just enough to level the sand. From the indicators on the container, read the top surface of the sand to the nearest .001 cubic foot. Repeat 2 times. Record the average of the 3 readings on line 1 of the Compaction Control Data Sheet. (No individual reading should be greater than .001 cubic foot more or less than the average of the 3 readings.)

<u>LINE 2 WEIGH PLUS 3/4</u> - Sieve the soil material removed from the measured hole through a 3/4 inch sieve. Weigh and record the material retained on the 3/4 inch sieve to the nearest hundredth of a pound.

<u>LINE 3 WEIGH MINUS 3/4</u> - Weigh and record the material passing the 3/4 inch sieve to the nearest hundredth of a pound. Reserve a portion of this material in a covered container to be used if it is later found necessary to determine the moisture content.

<u>LINE 4 FIELD WET DENSITY</u> - Using the Slide Rule Calculator in accordance with the instruction printed on the face of the Calculator, read and record the Field Wet Density (-3/4 in. fraction) to the nearest pound per cubic foot.

-Formula Used-

$$\text{FIELD WET DENSITY} = \frac{\text{Weight Minus } 3/4}{\text{Volume Hole} - \dfrac{\text{Weight Plus } 3/4}{2.65 \times 62.4}}$$

Compact the minus 3/4 inch material in the cylinder. Remove the collar and trim the sample level with the top of the cylinder. Remove the cylinder base plate.

LINE 5 WEIGH CYLINDER AND SOIL - Weigh the Cylinder and Soil and record the weight to the nearest tenth of a pound.

LINE 6 MINIMUM DENSITY SPECIFIED - % - The minimum requirement is indicated in the specifications and depends upon whether the layer being compacted and tested is in the embankment, subgrade or backfill. Record here.

LINE 7 MINIMUM MOISTURE CONTENT USED - Use 2 percent as the Minimum Moisture Content, unless the Regional Soils Engineer has established a higher minimum moisture content.

LINE 8 COMPACTION CONTROL TABLE NUMBER - From the Soil Type, determine the proper table to use for this test. Record here.

LINE 9 HIGHEST FIELD WET DENSITY REQUIRED - From the proper table, using the Weight of Cylinder and Soil (Line 5) and the Minimum Density Specified (Line 6) read and record the highest wet density indicated. Disregard wet densities for moisture contents below the Minimum Moisture Content (Line 7).

LINE 10 LOWEST FIELD WET DENSITY ALLOWED - Using the same input as for Line 9 read and record the lowest wet density indicated.

LINE 11 PASS - If the Field Wet Density (Line 4) is equal to or greater than the Highest Field Wet Density Required (Line 9) the test passes without further examination. Record here.

LINE 12 FAIL - If the Field Wet Density (Line 4) is less than the Lowest Field Wet Density allowed (Line 10) the test fails without further examination. Record here.

LINE 13 RUN MOISTURE - If the Field Wet Density (Line 4) is between the Highest Field Wet Density Required (Line 9) and the Lowest Field Wet Density Allowed (Line 10) it is necessary to determine the Moisture Content of the soil. Record here.

Using the portion of the moist minus 3/4 inch soil that was reserved as described in Line 3, weigh out a 500 gram sample (700 grams including the tare weight). The sample is then dried to a constant weight on the stove.

<u>LINE 14 WEIGH DRY SOIL AND TARE</u> - Weigh and record the Dry Soil and Tare to the nearest gram.

<u>LINE 15 PERCENT OF MOISTURE</u> - From the Percent of Moisture Table, using the Weight of Dry Soil and Tare (Line 14) record the Percent of Moisture to the nearest percent. If, after interpolation, the moisture content ends with .5, round off to the nearest <u>even</u> whole number.

<u>LINE 16 FIELD WET DENSITY REQUIRED</u> - From the proper Compaction Table (Line 8) using the Weight of Cylinder and Soil (Line 5) and the Percent of Moisture (Line 15) record the Field Wet Density Required. Interpolate for an odd-numbered moisture content.

<u>LINE 17 PASS</u> - If the Field Wet Density (Line 4) is equal to or greater than the Field Wet Density Required (Line 16) the test passes. Record here.

<u>LINE 18 FAIL</u> - If the Field Wet Density (Line 4) is less than the Field Wet Density Required (Line 16) the test fails. Record here.

If a compaction control test fails, the compaction operations on the layer must continue until another test indicates results in conformance with the Specifications. A review of the compaction operation may reveal that it is necessary for the Contractor to adjust or revise his methods and/or equipment in order to efficiently meet the requirements of the Specifications. Retested areas should be referenced to previously failing tests.

RECORDS

Form -2 must be filled out in triplicate and distributed each week as follows:

a. The Regional Construction Engineer
b. The Regional Soils Engineer
c. Project Files

All density tests made during the week should be reported, including those tests which failed. Also, record where retests were made after corrective measures were taken. Ample notes should be included on the form to identify the individual tests.

During periods when no grading is done, Form -2 should be sent in, regardless, with an explanation, thus providing a continuous documentation of the grading and compaction control operations on the project.

SANDS AND SANDS CONTAINING MINOR AMOUNTS OF GRAVEL AND SILT

WEIGHT OF CYLINDER AND SOIL - LBS.	MAX. DEN. SPECIFIED	MOISTURE CONTENT 2	4	6	8	10	12	14	16	18	20
	100%										
9.0	95%										
	90%										
	100%										
.9	95%										
	90%										
	100%										
.8	95%										
	90%										
	100%										
.7	95%										
	90%										
	100%	143	141	140	139	140					
.6	95%	136	134	133	132	133					
	90%	129	127	126	125	126					
	100%	140	139	137	136	137					
.5	95%	133	132	130	128	130					
	90%	126	125	123	121	123					
	100%	137	136	135	133	132	134				
.4	95%	130	129	128	127	126	128				
	90%	123	122	121	120	119	121				
	100%	134	133	132	131	129	130	131			
.3	95%	128	127	126	125	123	124	125			
	90%	121	120	119	118	116	117	118			
	100%	131	130	129	128	127	126	127	129		
.2	95%	125	124	123	122	121	120	121	123		
	90%	118	117	116	115	114	113	114	116		
	100%	129	128	127	125	124	123	123	125		
.1	95%	123	122	121	119	118	117	117	119		
	90%	116	115	114	112	112	111	111	113		
	100%	126	125	124	123	121	120	120	121	123	
8.0	95%	120	119	118	117	115	114	114	115	117	
	90%	113	112	112	111	109	108	108	109	111	
	100%	122	122	121	120	119	118	117	118	118	
.9	95%	116	116	115	114	113	112	111	112	112	
	90%	110	110	109	108	107	106	105	106	106	
	100%	119	119	118	117	116	116	115	115	115	116
.8	95%	113	113	112	111	110	110	109	109	109	110
	90%	107	107	106	105	104	104	103	103	103	104
	100%	116	116	116	115	114	113	112	111	111	112
.7	95%	110	110	110	109	109	108	107	106	106	107
	90%	104	104	104	103	103	102	101	100	100	101
	100%	112	112	112	112	111	110	109	109	109	108
.6	95%	107	107	107	107	106	105	104	104	104	103
	90%	101	101	101	101	100	99	98	98	98	97
	100%	109	109	109	109	108	107	106	106		
.5	95%	104	104	104	104	103	102	101	101		
	90%	98	98	98	98	97	96	95	95		
	100%	106	106	106	106	106					
.4	95%	101	101	101	101	101					
	90%	95	95	95	95	95					
	100%	104	104	104	104						
.3	95%	99	99	99	99						
	90%	94	94	94	94						
	100%	101	101	101							
.2	95%	96	96	96							
	90%	91	91	91							
	100%										
.1	95%										
	90%										
	100%										
7.0	95%										
	90%										

TABLE I

TILLS, SILTS, CLAYS, AND WELL GRADED GRAVELS

WEIGHT OF CYLINDER AND SOIL - LBS.	MAX. DEN. SPECIFIED	MOISTURE CONTENT 2	4	6	8	10	12	14	16	18	20	22	24	26	28	30
	100%	155	152	150	151											
9.0	95%	147	145	143	144											
	90%	139	137	135	136											
	100%	153	150	147	147	151										
.9	95%	146	143	140	140	144										
	90%	138	135	132	132	136										
	100%	151	148	146	144	146										
.8	95%	144	141	139	137	139										
	90%	136	133	131	130	131										
	100%	149	146	144	142	141	145									
.7	95%	142	139	137	135	134	136									
	90%	134	131	130	128	127	129									
	100%	148	144	142	140	138	138	142								
.6	95%	140	137	135	133	131	131	135								
	90%	133	130	128	126	124	124	128								
	100%	146	142	140	138	136	135	136	139							
.5	95%	138	135	133	131	129	128	129	132							
	90%	131	128	126	124	122	121	122	125							
	100%	143	140	138	136	134	133	132	134	136						
.4	95%	136	133	131	129	128	127	126	128	129						
	90%	129	126	124	122	121	120	119	121	122						
	100%	141	138	136	133	132	130	129	129	130	133					
.3	95%	134	131	129	127	126	124	123	123	124	127					
	90%	127	124	122	120	119	117	116	116	117	120					
	100%	139	136	133	131	130	129	128	127	126	126	128	130			
.2	95%	132	129	127	125	124	123	122	121	120	120	122	124			
	90%	125	122	120	118	117	116	115	114	113	113	115	117			
	100%	138	135	132	130	128	127	125	124	124	123	123	124	126		
.1	95%	131	128	126	124	122	121	119	118	118	117	117	118	120		
	90%	124	121	119	117	115	114	113	112	112	111	111	112	113		
	100%	136	132	130	128	126	124	124	123	122	121	121	120	120	121	
8.0	95%	129	126	124	122	120	118	118	117	116	115	115	114	114	115	
	90%	122	119	117	115	113	112	112	111	110	109	109	108	108	109	
	100%	133	130	127	126	124	123	122	121	120	120	119	119	118	118	117
.9	95%	127	124	121	120	118	117	116	115	114	114	113	113	112	112	111
	90%	120	117	114	113	112	111	110	109	108	108	107	107	106	106	105
	100%	130	127	125	124	122	120	120	119	118	118	117	116	116	115	115
.8	95%	124	121	119	118	116	114	114	113	112	112	111	110	110	109	109
	90%	117	114	113	112	110	108	108	107	106	106	105	104	104	103	103
	100%	128	125	123	122	120	119	118	117	117	116	115	114	114		
.7	95%	122	119	117	116	114	113	112	111	111	110	109	109	109		
	90%	115	112	111	110	108	107	106	105	105	104	103	103	103		
	100%	125	123	121	119	118	117	116	116	115	114	113	113			
.6	95%	119	117	115	113	112	111	110	110	109	109	108	108			
	90%	112	111	109	107	106	105	104	104	103	103	102	102			
	100%	122	120	119	117	116	115	114	113	113	112	111				
.5	95%	116	114	113	111	110	109	109	108	108	107	106				
	90%	110	108	107	105	104	103	103	102	102	101	100				
	100%	120	118	116	115	114	113	112	112	111	110	110				
.4	95%	114	112	110	109	109	108	107	107	106	105	105				
	90%	108	106	104	103	103	102	101	101	100	99	99				
	100%	117	116	114	112	111	110	110	109	109	109					
.3	95%	111	110	109	107	106	105	105	104	104	104					
	90%	105	104	103	101	100	99	99	98	98	98					
	100%	115	113	112	111	110	109	109	108	108						
.2	95%	109	108	107	106	105	104	104	103	103						
	90%	103	102	101	100	99	98	98	97	97						
	100%															
.1	95%															
	90%															
	100%															
7.0	95%															
	90%															

TABLE II

FIELD WET DENSITIES REQUIRED

(TO OBTAIN THE MAXIMUM DENSITY SPECIFIED)

EXAMPLE

DATA	SOLUTION
SOIL TYPE -------- SILT	COMPACTION CONTROL TABLE -- II
WT. CYLINDER & SOIL - 8.1 LBS.	HIGHEST WET DEN. REQUIRED--- 124 LBS./C.F.
MAX. DEN. SPECIFIED-- 95%	LOWEST WET DEN. ALLOWED --- 117 LBS./C.F.
MIN. MOISTURE USED - 8 %	

NEW YORK STATE
DEPARTMENT OF TRANSPORTATION

COMPACTION CONTROL TABLES

FORM I

Form 1 (Front)

WEIGHT OF DRY SOIL AND TARE GRAMS

MOISTURE CONTENT PERCENT

USE 500 GRAM SAMPLE AND 200 GRAM TARE

WEIGHT OF DRY SOIL AND TARE GRAMS	MOISTURE CONTENT PERCENT
700	0
695	1
690	2
685	3
681	4
676	5
672	6
667	7
663	8
659	9
655	10
650	11
646	12
642	13
639	14
635	15
631	16
627	17
624	18
620	19
617	20
613	21
610	22
606	23
603	24
600	25
597	26
594	27
591	28
588	29
585	30
582	31
579	32
576	33
573	34
570	35
568	36
565	37
562	38
560	39
557	40

MOISTURE CONTENT TABLE

Form 1 (Back)

NEW YORK STATE DEPARTMENT OF TRANSPORTATION
COMPACTION CONTROL DATA SHEET

PIN	PROJECT	
COUNTY	CONTRACT NO.	INSPECTOR

	DATE OF TEST						
	TEST NUMBER						
	STATION OF TEST						
	OFFSET						
	TYPE AND WEIGHT OF COMPACTOR						
	NUMBER OF PASSES PER LAYER						
	SOIL TYPE (SAND) (TILL-SILT-CLAY-GRAVEL)	SAND		TILL		SILT	
	DEPTH BELOW SUBGRADE SURFACE	4.0		6.0		1.0	
1	MEASURE VOLUME OF HOLE - CF	.072		.068		.082	
2	WEIGH PLUS 3/4 - LBS	1.51		2.32		0	
3	WEIGH MINUS 3/4 - LBS	7.40		6.68		9.83	
	FROM CALCULATOR						
4	FIELD WET DENSITY	118		124		120	
5	WEIGH CYLINDER AND SOIL - LBS	7.9		8.3		8.1	
6	MAXIMUM DENSITY REQUIRED - %	90		90		95	
7	MINIMUM MOISTURE CONTENT USED - %	2		8		6	
8	COMPACTION CONTROL TABLE NUMBER	I		II		II	
	FROM TABLES						
9	HIGHEST FIELD WET DEN. REQUIRED	110		120		126	
10	LOWEST FIELD WET DEN. ALLOWED	105		116		117	
11	PASS (LINE 4 EQUAL OR GREATER THAN LINE 9)	✓		✓			
12	FAIL (LINE 4 LESS THAN LINE 10)						
13	RUN MOISTURE (USE 500 GRAM SAMPLE)					✓	
14	WEIGH DRY SOIL AND TARE - GRAMS					645	
	FROM TABLES						
15	MOISTURE CONTENT - %					12	
16	FIELD WET DENSITY REQUIRED					121	
17	PASS (LINE 4 EQUAL OR GREATER THAN LINE 16)						
18	FAIL (LINE 4 LESS THAN LINE 16)					✓	

REMARKS:

Form 2

CONCLUSIONS

Although the new features described in this report are best utilized in combination with this test method, they can be independently evaluated and if desired, they can be incorporated individually into other test methods.

The direct reading *Volumeter* is accurate and rapid. It is simple to operate, relatively maintenance free and inexpensive to purchase.

The *Slide Rule* is especially designed for a specific purpose. There is no better way to determine the field wet density corrected for plus 3/4 inch material.

Fixed Weight Tares have been used to good advantage in other tests. The benefits derived in a compaction control test are apparent.

The simplifying *Percent of Moisture Table* is made possible by the use of a fixed weight for the moist soil sample.

The development of *Required Wet Density Tables* from moisture-density curves is a major evolution in the quality control of earthwork construction.

Instructions for the proposed test method are uncomplicated and straightforward. The procedures can *vertually eliminate the need to make moisture content determinations.*

From the Comparison of the Steps Required by Compaction Test Methods (Figure 9) it can be readily seen that the *time necessary to perform a test has been materially reduced* and that the simplification of the test provides a corresponding *reduction in the probability of errors.*